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**BOX: PATENT APPLICATION**

Assistant Commissioner for Patents  
Washington, D.C. 20231

Re: Application of Shuji HITOMI  
**ELECTRODE FOR FUEL CELL AND MANUFACTURING METHOD THEREFOR**  
Our Reference: Q57834

Dear Sir:

Attached hereto is the application identified above including the specification, claims, executed Declaration and Power of Attorney, ten (10) sheets of drawings, executed Assignment and PTO Form 1595.

The Government filing fee is calculated as follows:

Total Claims	29 - 20 =	9 x \$18 =	\$ 162.00
Independent Claims	8 - 3 =	5 x \$78 =	\$ 390.00
Base Filing Fee	(\$690.00)		\$ 690.00
Multiple Dep. Claim Fee	(\$260.00)		\$ 260.00
<b>TOTAL FILING FEE</b>			<b>\$ 1,502.00</b>
Recordation of Assignment Fee			\$ 40.00
<b>TOTAL U.S. GOVERNMENT FEE</b>			<b>\$ 1,542.00</b>

Checks for the statutory filing fee of \$ 1,502.00 and Assignment recordation fee of \$ 40.00 are attached. You are also directed and authorized to charge or credit any difference or overpayment to Deposit Account No. 19-4880. The Commissioner is hereby authorized to charge any fees under 37 C.F.R. 1.16 and 1.17 and any petitions for extension of time under 37 C.F.R. 1.136 which may be required during the entire pendency of the application to Deposit Account No. 19-4880. A duplicate copy of this transmittal letter is attached.

Priority is claimed from:

Japanese Patent Application  
P.Hei. 11-29045  
P.Hei. 11-78885  
P.Hei. 11-78889

Filing Date  
February 5, 1999  
March 24, 1999  
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The priority documents will be submitted at a later date.

Respectfully submitted,  
SUGHRUE, MION, ZINN, MACPEAK & SEAS  
Attorneys for Applicant(s)

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DM:clf

# ELECTRODE FOR FUEL CELL AND MANUFACTURING METHOD THEREFOR

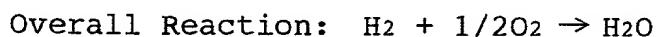
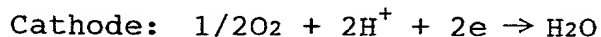
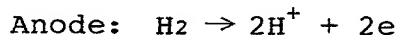
## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates to an electrode for a fuel  
5 cell and a manufacturing method therefor.

### 2. Description of the Related Art

A solid polymer electrolyte fuel cell is an apparatus  
comprising membrane-electrode assembly, which comprises  
electrodes, an anode and a cathode each having a catalyst layer  
10 and a gas diffusion layer containing an electron-conductive  
porous substrate, bonded onto ion-exchange membrane.  
Hydrogen is supplied to the anode and oxygen is supplied to  
the cathode so as to generate electric power by using  
electrochemical reactions. The electro-chemical reaction  
15 which occurs in each electrode is as follows:



As can be understood from the reaction formula, reactions  
20 in each electrode proceed in only the three-phase boundary  
sites in which supply and receipt of reactant gases (hydrogen  
or oxygen), protons ( $\text{H}^+$ ) and electrons ( $\text{e}$ ) can simultaneously  
be performed.

As shown in Fig. 8, the electrode of a fuel cell  
25 incorporates a porous catalyst layer 86 in which catalyst  
particles 81 and solid polymer electrolyte 82 are distributed  
three-dimensionally with a plurality of small pores 84 are

formed; and a gas diffusion layer 88 containing a  
electro-conductive porous substance 87.

The gas diffusion layer 88 provides spaces in the surface  
of the catalyst layer 86 to maintain a passage for carrying  
5 oxygen or hydrogen as a reactant supplied from the outside  
of the cell. Moreover, the gas diffusion layer 88 provides  
a passage for discharging water produced in the catalyst layer  
of the anode from the surface of the catalyst layer 86 to the  
outside of the cell system.

On the other hand, the catalyst particles 81 of the  
catalyst layer 86 form electron conductive channel, the solid  
polymer electrolyte 82 forms a proton conductive channel and  
the small pores 84 form supply/discharge channel for supplying  
oxygen or hydrogen to the inside from the surface of the  
15 catalyst layer 86 and discharging water produced in the  
cathode to the surface for the inside of the catalyst layer.  
The three channels are three-dimensionally dispersed in the  
catalyst layer 86 so that an infinite number of three-phase  
boundary sites, in which the gas, protons ( $H^+$ ) and electrons  
20 (e) are supplied and receipted simultaneously, are formed in  
the catalyst layer 86. Thus, portions for the reaction sites  
of the electrode is provided.

Note that reference numeral 83 shown in Fig. 8  
represents PTFE (polytetrafluoroethylene) particles which  
25 impart hydrophobicity to the inside portion of the small  
pores 84 of the catalyst layer 86 and the surface of the small

pores 84. Reference numeral 85 represents an ion-exchange membrane.

The ion-exchange membrane 85 serving as an electrolyte exhibits satisfactory proton conductivity in a water-  
5 retention state. Therefore, the operation must be performed while a wet state is being maintained in the cell. Therefore, humidified hydrogen or oxygen are supplied to the anode or the cathode to prevent dry up of the ion-exchange membrane 85 so that water content in the ion-exchange membrane is  
10 controlled.

The solid polymer electrolyte fuel cell has the catalyst layer with the pores forming three-dimensional channel for supplying oxygen or hydrogen. Therefore, the humidified supply gas, which is the reactant, causes water to be  
15 accumulated in the surface of the catalyst layer. As an alternative to this, accumulation of water in the pores inhibits supply of the reactant gases to the three-phase boundary sites of the catalyst layer, and, in particular, to the deep portion of the electrode. Thus, an actual active  
20 surface area is reduced. Therefore, the performance of the cell cannot satisfactorily be obtained. Accordingly, adequate hydrophobicity is imparted to the gas diffusion layer containing the electro-conductive porous substance and the catalyst layer to prevent accumulation of water.

25 The hydrophobicity to the electro-conductive porous substance in a case of carbon paper (having a thickness of 1.5 mm) which is made by a sintering body of carbon fibers

will now be described. The carbon paper is immersed in solution of PTFE suspension. Then, the carbon paper containing the PTFE particles are baked at about 350°C for 15 minutes in a nitrogen atmosphere so that the surfaces of the carbon fibers are coated with PTFE.

On the other hand, the hydrophobicity is imparted to the catalyst layer by mixing the PTFE suspension into paste for the catalyst layer including carbon particles supporting fine particles of noble metal as catalyst, such as platinum, and the solid polymer electrolyte solution.

The hydrophobicity of both of the catalyst layer and the electro-conductive porous substance is, however, unsatisfactory at present. Supply of hot and enough humidified gases to improve the proton conductivity of the ion-exchange membrane resulting in enhancement of cell power unsatisfactorily causes water to be water flooding accumulated in the pores of the catalyst layer and the surface of the same. As a result, supply of the reactant gases to the three-phase boundary sites of the catalyst layer, and, in particular, to deep portions of the catalyst layer is inhibited. As a result, the actual active surface area is reduced, causing a problem to arise in that the performance of the cell cannot sufficiently be obtained. In particular, because water is produced with the reactions proceeding, this accumulation of water is occurred easily in the pores of the catalyst layer in the cathode.

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To improve the hydrophobicity of the catalyst layer, resulting in solution of the foregoing problem, the mixture ratio of the solution of PTFE particles dispersion to the past for the catalyst layer must be increased. However, the increase of the amount of the PTFE particles in the electrode reduces the ratio of the catalyst supporting on carbon, the solid polymer electrolyte and the pores. As a result, formation of the electron conductive channel, the proton conductive channel and the channel for supplying/discharging oxygen or hydrogen as a reactant and water which is a product is inhibited. Therefore, there arises a problem in that the power of the cell is undesirably reduced.

To furthermore improve the hydrophobicity of the electro-conductive porous substance, the amount of PTFE suspension which is applied to the electro-conductive porous substance must be increased. If the amount of it is enlarged excessively, PTFE particles close pores of the electro-conductive porous substance. In the foregoing case, there arises a problem in that gas supply is inhibited.

In general, it is said that the effective thickness of the catalyst layer for the electrochemical reactions is 5 m to 10 m. The gas supply in the electrode cannot sufficiently be performed in the catalyst layer having a larger thickness. As a result, the gas is wasted and the function of the electro-conductive porous substance for maintaining the passage for the gas is inhibited. Therefore,

control of the thickness of the catalyst layer is an important factor to improve the performance of the electrode.

However, in general, carbon paper which is the conventional electro-conductive porous substance is manufactured by molding carbon fibers each having a diameter of 5  $\mu\text{m}$  to 10  $\mu\text{m}$  into an unwoven shape, followed by sintering. The average diameter of the pores of the substrate is about 10  $\mu\text{m}$  to about 20  $\mu\text{m}$ . Therefore, it is very difficult to keep the thickness of 5  $\mu\text{m}$  to 10  $\mu\text{m}$  of the catalyst layer.

A cross section of a state where the conventional catalyst layer has been formed on the carbon paper gas diffusion layer is shown in Fig. 9. Reference numeral 91 represents the catalyst layer and 92 represents the carbon paper as the electro-conductive porous substance. Since the diameter of the pores in the electro-chemical reactions made of the porous material is large and its pores are roughly distributed, the thickness of the applied catalyst layer 91 is ununiform.

To prevent the foregoing problem, the porosity and its pore diameter of the porous substance must be reduced and a dense structure must be formed. In the foregoing case, the passage for the gas cannot easily be maintained.

#### SUMMARY OF THE INVENTION

In view of the foregoing, an object of the present invention is to advance the performance of an electrode for a fuel cell by improving the hydrophobicity while a gas

diffusivity of the gas diffusion electrode for a fuel cell is being maintained. Another object of the present invention is to improve the performance of an electrode for a fuel cell by densely forming a electro-conductive porous substance to uniform the thicknesses of the catalyst layer while a gas diffusivity of the gas diffusion layer is being maintained.

According to the present invention, an electrode for a fuel cell comprises a catalyst layer containing a solid polymer electrolyte, catalyst particles and porous polymer (a) alternatively, an electrode for a fuel cell comprises a catalyst layer containing a solid polymer electrolyte and catalyst particles, wherein porous polymer is provided for the inside portions of pores of the catalyst layer or/and the surface of the catalyst layer. An electrode for a fuel cell comprises a catalyst layer containing a solid polymer electrolyte and catalyst particles; and a gas diffusion layer containing electro-conductive porous substance, wherein the catalyst layer or/and electro-conductive porous substance incorporate porous polymer. It is preferable that the porous polymer is fluorocarbon polymer.

#### BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

Fig. 1 is a graph showing I-V characteristics of cells A to D;



Fig. 2 is a graph showing I-V characteristics of cells E and G;

Fig. 3 is a graph showing I-V characteristics of cells H and I;

5 Fig. 4 is a schematic view showing the structure of an electrode for a fuel cell according to the present invention;

Fig. 5 is a schematic view showing the structure of the electrode for a fuel cell according to the present invention;

10 Fig. 6 is a schematic view showing the structure of the electrode for a fuel cell according to the present invention;

Fig. 7 is a schematic view showing the structure of the electrode for a fuel cell according to the present invention;

Fig. 8 is a schematic view showing the structure of a conventional electrode for a fuel cell;

15 Fig. 9 is a schematic view showing the cross-sectional structure of a conductive base of the conventional electrode for a fuel cell; and

Fig. 10 is a schematic view showing the cross-sectional structure of porous polymer according to the present  
20 invention.

#### DETAILED DESCRIPTION OF THE DRAWINGS

The present invention will be described as follows referring to the accompanying drawings.

25 An example of the structure of an electrode for a fuel cell according to the present invention will now be described to furthermore specifically describe the present invention.

Figs. 4, 5 and 6 are schematic views showing examples of structures of the electrode for a fuel cell according to the present invention.

As shown in Figs. 4, 5 and 6, a catalyst layer according to the present invention and containing a solid polymer electrolyte and catalyst particles and plural porous catalyst layer. The catalyst layer has a structure that catalyst particles 41, 51 and 61 and solid polymer electrolytes 42, 52 and 62 are distributed three-dimensionally with a plurality of small pores 43, 53 and 63 in the catalyst layer. The average diameter of the small pore is from 10nm to 1 $\mu$ m. Basically, the catalyst particles form an electron conductive channel and the pores for a channel for supplying and discharging oxygen or hydrogen and water which is a product.

In case of the electrode for a fuel cell shown in Fig. 4, porous polymer 44 with three-dimensional network pore (hereinafter referred to as "porous polymer") exist mainly at the small pores in the catalyst layer. The electrode for a fuel cell shown in Fig. 5 includes porous polymer 54 with three-dimensional network pore at the surface of the catalyst layer. An electrode for a fuel cell shown in Fig. 6 includes porous polymer 64 with three-dimensional network pore existing at both the small pores and the surface of the catalyst layer. If necessary, each of the foregoing electrodes for fuel cells are able to incorporate the catalyst layer and the gas diffusion layer with the

electro-conductive porous substance with the porous polymer at same time. Referring to the figures above, reference numerals 45, 55 and 65 represent ion-exchange membranes and each of 46, 56 and 66 represents a carbon porous material made by sintering of carbon fibers as an electro-conductive substrate. If necessary, PTFE particles may be provided the catalyst layer similarly to the conventional technique.

According to the present invention, it is not necessary that the porous polymer having ion-exchange function is provided for the small pores in the catalyst layer or/and the surface of its layer. Therefore, the hydrophobicity of the small pores or/and the surface of the catalyst layer can be improved. As a result, accumulation of water in the surface of the catalyst layer causing the small pores to be closed can be prevented. Also accumulation of water in the small pores can be prevented. Therefore, the gases, which is reactants, can smoothly be supplied to the three-phase boundary sites of the catalyst layer. Hence it follows that the catalyst layer can satisfactorily be activated.

Although the effect of the present invention can be obtained when the porous polymer is provided for only the inside portions of the pores as shown in Fig. 4 or when the porous polymer is provided for only the surface as shown in Fig. 5, a furthermore satisfactory activation can be realized when the porous polymer is provided for both the small pores and the surface of the catalyst layer as shown in Fig. 6.

Although the porous polymer may be provided for the overall inside of the small pores or/and surface of the matrix of the catalyst layer as shown in the foregoing drawings, the porous polymer may be provided for a portion of the surface or/and a portion of the inside of the small pores.

Fig. 7 is a schematic view showing the structure of an electrode for a fuel cell according to the present invention, incorporating a catalyst layer, containing a solid polymer electrolyte and catalyst particles, and a gas diffusion layer, containing the electro-conductive porous substance, the structure being characterized in that the electro-conductive porous substance includes the porous polymer. Referring to Fig. 7, reference numeral 71 represents a catalyst layer of the electrode, 72 represents the electro-conductive porous substance such as carbon paper or carbon cloth and 73 represents the porous polymer. Since the conductive porous material according to the present invention includes the porous polymer in the pores thereof, a dense structure can be formed. Therefore, the thicknesses of the catalyst layer of the electrode can substantially be uniformed.

A preferred material for forming the catalyst particles for use as the electrode according to the present invention is any one of platinum metal particle, such as platinum, rhodium, ruthenium, iridium, palladium or osmium, their alloy particles or the foregoing catalyst supported on carbon particle. The solid polymer electrolyte is a solid polymer

electrolyte having proton conductivity. It is preferable that the solid polymer electrolyte is constituted by ion-exchange resin. It is preferable that sulfon type ion-exchange resin is employed which is made of

5 perfluorosulfonic acid or polystyrene sulfonic acid type. Although the porous substrate according to the present invention may be made of foam nickel or sintered body of titanium fibers, it is preferable that a carbon material which is a sintered body of carbon fibers or the like, such  
10 as carbonpaper or carbon cloth, is employed from a viewpoint of obtaining satisfactory electro-conductivity.

The polymer according to the present invention is polymer which does not always has no proton conductivity and exemplified by polyvinyl chloride, polyacrylonitrile,  
15 polyethylene oxide or polypropylene oxide, polyacrylonitrile, poly vinylidene fluoride, polyvinylidene chloride, polymethyl methacrylate, polymethyl acrylate, polyvinyl alcohol, polymethacrylonitrile, polyvinyl acetate, polyvinyl  
20 pyrrolidone, polyethylene-imine, polybutadiene, polystyrene, polyisoprene or their derivatives. The foregoing materials may be employed solely or their mixtures may be employed. Resin prepared by copolymerizing a variety of monomers which constitute the foregoing polymer may be employed. It is  
25 preferable that fluoro carbon polymer exhibiting excellent hydrophobicity is employed, such as polychlorotrifluoroethylene (PCTFE), polyvinylidene fluoride (PVDF)

or polyvinyl fluoride (PVF); or copolymer containing fluorocarbon polymer, such as ethylene-tetrafluoro ethylene copolymer (ETFE) or ethylene tetrafluoride-propylene hexafluoride copolymer (EPE) or vinylidene fluoride-hexafluoropropylene copolymer (P(VdF-HFP)). Note that their mixtures maybe empolyed.

To realize smooth supply and discharge of the reactant gases, it is preferable that the small pores in the porous polymer are continuous three-dimensionally network structure such as shown in Fig. 10. As for the diameter of each pore, it is preferable that the average diameter of the pores is 1  $\mu$ m or smaller, more preferably 0.5  $\mu$ m or smaller, preferably 100nm or larger. Because average diameter of pores in electro-conductive substrate is about 10  $\mu$ m to 20  $\mu$ m. Furthermore, it is preferable that the average diameter of pores in porous polymer is 0.05  $\mu$ m or smaller, because average diameter of pores in catalyst layer is about 1  $\mu$ m to 2  $\mu$ m. It is preferable that the porosity of the porous polymer is not lower than 45 % nor higher than 95 % from a viewpoint of realizing smooth supply of gases and smooth discharge of water.

The porous polymer electrolyte according to the present invention is manufactured by phase-inversion process in which polymer (a) from solution (c) in which the polymer (a) is dissolved with lowering in solvent (b).

For example, the phase inversion occurs, by a method using change in the solubility of polymer (a) with lowering

the temperature of the solution (c) in a case of combination of the polymer (a) and the solvent (b) such that the polymer (a) cannot easily be dissolved in the solvent (b) at low temperature and the polymer (a) can be dissolved when the temperature has been raised will now be described. The phase inversion is a phenomenon that the polymer (a) with respect to the solvent (b) becomes supersaturated when the polymer (a) has completely been dissolved in the solvent (b) by raising the temperature followed by lowering the temperature of the solution (c) so that the polymer (a) and the solvent (b) are separated from each other with decreasing the solubility. Therefore, the porous polymer can be obtained.

As an alternative to this, the phase inversion occurs by a method using change in the concentration caused by vaporizing the solvent (b). Process is as follows. The polymer (a) is dissolved in a mixture containing a solvent (b) and non solvent (e). The non solvent (e) is less volatile than solvent (b), and the solvent (b) and the non solvent (e) must be miscible liquid. During the evaporation, the relative ratio of non solvent (e) increases leading to the polymer (a) precipitation. Therefore, porous polymer can be obtained.

It is preferable that the phase inversion by a solvent extraction method is employed as a method of manufacturing the porous polymer with which dense and continuous three-dimensional network pores can be obtained. That is, non solvent (d) which is insoluble in the polymer (a) and

soluble in the solvent (b), extract the solvent (b) from the solution (c) in which the polymer (a) has been dissolved by contact between solution (c) and non solvent (d). Thus, the porous polymer is obtained.

5       The polymer (a) according to the present invention is polymer which does not always have no proton conductivity and exemplified by polyvinyl chloride, polyacrylonitrile, polyethylene oxide or polypropyleneoxide, polyacrylonitrile, poly vinylidene fluoride, 10 polyvinylidene chloride, polymethyl methacrylate, polymethyl acrylate, polyvinyl alcohol, polymethacrylonitrile, polyvinyl acetate, polyvinyl pyrrolidone, polyethylene-imine, polybutadiene, polystyrene, polyisoprene or their derivatives. The 15 foregoing materials may be employed solely or their mixtures may be employed. Polymer prepared by copolymerizing a variety of monomers which constitute the foregoing polymer may be employed. It is preferable that fluorocarbon polymer exhibiting excellent hydrophobicity is employed, such as 20 polychloro-trifluoroethylene (PCTFE), polyvinylidene fluoride (PVdF) or polyvinyl fluoride (PVF); or copolymer containing fluorocarbon polymer, such as ethylene-tetrafluoro ethylene copolymer (ETFE) ethylene tetrafluoride-propylene hexafluoride copolymer (EPE), or 25 P(VdF) copolymer. Note that their mixtures may be employed.

The polymer (a) for use in a method of phase-inversion processed by change in the solubility, the polymer (a) from



the solution (c) in which the polymer (a) has been dissolved in the solvent (b) is preferably polyvinylidene fluoride (PVdF), P(VdF) copolymer, such as vinylidene fluoride /hexafluoropropylene copolymer (P(VdF-HFP).

5       The solvent (b) for dissolving the polymer (a) is exemplified by ketone, such as methyl ethyl ketone (MEK) or acetone; ester, such as propylene carbonate, ethylene carbonate, dimethyl carbonate, diethyl carbonate or ethylmethyl carbonate; ether such as dimethyl ether; diethyl  
10 ether; ethylmethyl ether; tetrahydrofuran; dimethylformamide; N-methylpyrrolidone (NMP). In particular, ketone is a preferred material. Among the ketone, it is preferable that methyl ethyl ketone (MEK) is employed.

15       When the porous fluorocarbon polymer is prepared as a polymer (a) by the phase inversion process using the above-mentioned solvent extraction method, dense and uniform pores can be formed. Therefore, it is preferable that the polymer (a) is polyvinylidene fluoride (PVdF) and  
20 P(VdF) copolymer such as vinylidene fluoride /hexafluoropropylene copolymer (P (VdF-HFP) or vinylidene fluoride-ethylene tetrafluoride (P (VdF-TFP). In particular, it is preferable for polymer (a) that polyvinylidene fluoride (PVdF) exhibiting excellent  
25 hydrophobicity or vinylidene fluoride /hexafluoropropylene copolymer (P (VdF-HFP) which is a soft material which permits easy handling is employed.

The solvent (b) for dissolving the polymer (a) is required to dissolve the polymer. The material is exemplified by ester, such as propylene carbonate, ethylene carbonate, dimethyl carbonate, diethyl carbonate or ethylmethyl carbonate; ether, such as dimethyl ether, diethyl ether, ethylmethyl ether or tetrahydrofuran (THF); ketone, such as methylethyl ketone or acetone; dimethylformamide; dimethyl acetoamide; 1-methylpyrrolidone; and N-methylpyrrolidone.

It is preferable that the extracting non solvent (d) is water or mixed solution of both water and alcohol because of cheaper.

When the foregoing materials are employed in the solvent extraction method, it is preferable that polyvinylidene fluoride (PVdF) or P (VdF-HFP), and solvent (b) is in N-methylpyrrolidone (NMP), and non solvent (d) is water or the mixed solution of water and alcohol from a viewpoint of obtaining excellent hydrophobicity and uniform diameters of the pores.

A method of manufacturing the electrode for a fuel cell according to the present invention and structured as described above will now be described. Paste for the catalyst layer consisting of catalyst supported on carbon particles, the solid polymer electrolyte solution and, if necessary, PTFE suspension is applied onto a polymer film to form a film of the paste (in general, having a thickness of 3  $\mu$ m to 30  $\mu$ m). Then, heating and drying are performed

so that the conventional catalyst layer can be obtained. As an alternative to this, paste of the catalyst layer consisting of catalyst supported on carbon particles (noble metal particles, such as platinum are highly dispersedly loaded on carbon particle) and, if necessary, solution PTFE suspension is applied onto the polymer film to form a film of the paste (in general, having a thickness of 3  $\mu$ m to 30  $\mu$ m). Then, heating and drying are performed. Then, the solid polymer electrolyte solution is applied and allowed to be impregnated from a position above the polymer film of the paste. Thus, the conventional catalyst layer can be obtained. If necessary, these above-mentioned conventional catalyst layers are joined to the ion-exchange membrane. After that, if necessary, the gas diffusion layer including electro-conductive porous substrate is joined to the surface of the catalyst layer. Then, the solution (c) in which the polymer (a) is dissolved in the solvent (b) is contained in the above-mentioned conventional catalyst layer. Then, the polymer (a) is separated from the solution (c) by phase inversion process so that the catalyst layer including porous polymer for a fuel cell's electrode is obtained. For example, catalyst layer including the solution (C) is immersed into the non solvent (d) which is insoluble in polymer (a) and soluble in the solvent (b). Thus, the catalyst layer for a fuel cell's electrode can be obtained by solvent extraction method. Then, the polymer (a) is phase-separated from the solution (c) so that the electrode for a fuel cell is obtained.

As an alternative to this, the solution (c) in which the polymer (a) is dissolved in the solvent (b) is contained by coating or immersion. Then, the non solvent (d) which is insoluble in polymer (a) and soluble in the solvent (b) is substituted for the polymer (a). Thus, the electrode for a fuel cell can be obtained.

As an alternative to this, paste of the catalyst layer consisting of catalyst supported on carbon particles, the solid polymer electrolyte solution and, if necessary, PTFE suspension is applied onto an electro-conductive porous substance to form a film of the paste (in general, having a thickness of 3  $\mu$ m to 30  $\mu$ m). Then, heating and drying are performed so that the conventional electrode is manufactured.

As an alternative to this, paste of the catalyst layer consisting of catalyst supported on carbon particles (noble metal particles, such as platinum, are highly dispersedly loaded on carbon particle) and, if necessary, PTFE suspension is applied onto electro-conductive porous substrate to form a film of the paste (in general, having a thickness of 3  $\mu$ m to 30  $\mu$ m). Then, heating and drying are performed. Then, the solid polymer electrolyte solution is applied and allowed to impregnate so that the conventional electrode is manufactured. If necessary, these above-mentioned conventional electrode are joined to the ion-exchange membrane.

Then, the solution (c) in which the polymer (a) is dissolved in the solvent (b) is contained in the above-

mentioned conventional electrode. Then, the polymer (a) is separated from the solution (c) by phase inversion process. Thus, the electrode including porous polymer for a fuel cell can be obtained. For example, the above-mentioned  
5 electrode including solvent (c) is immersed into the non solvent (d) which is insoluble in the polymer (a) and soluble in the solvent (b) so that the electrode according to the present invention for a fuel cell is manufactured.

When the latter manufacturing method is employed, the  
10 electrode for a fuel cell, consisting of the catalyst layer containing the solid polymer electrolyte and the catalyst particles and the gas diffusion electrode containing the electro-conductive porous substance has the structure that both the catalyst layer and the electro-conductive porous  
15 substance contain the porous polymer. Therefore, an electrode for a fuel cell exhibiting high activity can be manufactured. When fluorocarbon polymer exhibiting excellent hydrophobicity is employed, a necessity for previously imparting the hydrophobicity to the electro-  
20 conductive porous substance can be eliminated. Because in the foregoing case, the porous polymer provided for the electro-conductive porous substance acts as a hydrophobic material.

A method of manufacturing the electrode for fuel cell  
25 according to the present invention, which has porous polymer in the electro-conductive porous substrate of the gas diffusion layer, will be described.

The solution (c), in which the polymer (a) is dissolved in the solvent (b), is contained in the electro-conductive porous substrate. Then, the polymer (a) is separated from the solution (c) using the phase inversion process by change in the solubility on change in the concentration as described above.

As an alternative to this, the solution (c), in which the polymer (a) is dissolved in the solvent (b), is contained to electro-conductive substrate. Then, the electro-conductive porous substrate containing solution (c) is immersed into non solvent (d), which is insoluble in the polymer (a) and soluble in the solvent (b). Thus, the electro-conductive substrate including the porous polymer is obtained.

Then, a method is employed with which paste of the catalyst layer including catalyst supported on carbon particles, the solid polymer electrolyte solution and, if necessary PTFE (polytetrafluoroethylene) is applied onto the electro-conductive porous substance by a brush or by spraying is employed. As an alternative to this, a film of the paste of catalyst layer is directly formed on the surface of the electro-conductive porous substance by a screen printing method or a doctor blade method. As an alternative to this, a method may be employed with which a catalyst layer formed on a polymer film or metallic foil as a blank is transferred to the electro-conductive porous substance by a hot press method or the like and then the blank is removed

away. As an alternative to this, a method may be employed with which the catalyst layer is joined to the surface of the ion-exchange membrane by the foregoing method or the like. Then, the electro-conductive porous substance including the porous polymer provided for the surface of catalyst layer thereof is hot-pressed or pressed.

If the method of manufacturing an electrode of the present invention for a fuel cell is used which is characterized in that when the porous polymer contains fluorocarbon polymer, furthermore excellent hydrophobicity can be obtained by fluorination of the fluorocarbon polymer ("fluorination of the fluorocarbon" is substitution of a fluorine atom for another atom (for example, a hydrogen atom or a chlorine atom). Fluorocarbon polymer includes polytetrafluoroethylene or tetrafluoroethylene-hexafluoropropylene (PTFE) or tetrafluoroethylene-hexafluoropropylene copolymer (EPE) which consists of only both carbon atoms and fluorine atoms. Since the foregoing material cannot furthermore be fluoridated, the foregoing materials are omitted from the scope of the present invention. It is preferable that the fluoropolymer is polymer containing such as polychlorotrifluoro ethylene copolymer (PCTFE), polyvinylidene fluoride (PVdF) or polyvinylidene fluoride (PVF), vinylidene fluoride/hexafluoropropylene copolymer P(VdF/HFP), ethylene-tetrafluoroethylene copolymer (ETFE) or ethylene-chlorotrifluoroethylene copolymer (ECTFE). Their mixtures may be employed.

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The process for fluorination of the porous fluorocarbon polymer is performed by substitution fluorine (F) for another atom, such as hydrogen (H) or chlorine (Cl), joined to carbon skeletons of the fluorocarbon polymer. For example, when  
5 the porous fluorocarbon polymer is exposed to fluorine gas, the foregoing process can be performed while the porosity is being maintained. When the substitution ratio of fluorine (F) of the fluorocarbon polymer for hydrogen (H) and chlorine (Cl), is adjusted by change in contact time  
10 between fluorocarbon resin and fluorine gas, the hydrophobicity can be controlled. Although fluorocarbon polymer has somewhat hydrophobicity, the process for furthermore fluorinating the fluoro carbon polymer as described above enables higher hydrophobicity to be  
15 obtained.

#### [Examples]

Examples of the present invention will now be described.

#### [Example 1]

Paste of a catalyst layer composed of platinum supported  
20 on carbon (10V30E: 30wt%Pt supported on Valcan XC-72 manufactured by Tanaka Kikinzoku) and solid polymer electrolyte solution (5 wt% Nafion solution manufactured by Ardrich) was applied to the surface of a carbon sheet (0.5 mm) as an electro-conductive porous substrate to form  
25 the film of the paste. Then, the paste was dried at 120°C for one hour in a nitrogen atmosphere. Thus, an electrode was obtained. The electrode was impregnated with PVdF/NMP



solution (the concentration of PVdF: 15 wt%) in a vacuum, and then immersed in water for 10 minutes. Thus, electrode A for a fuel cell was obtained.

The electrode A has a structure that the porous PVdF is provided for the inside portions of pores and the surface of the catalyst layer, inside of the electro-conductive porous substance.

The amount of the platinum supported on carbon in the paste was adjusted when the paste was prepared so that the amount of platinum loading of the electrode A was about 1.0 mg/cm<sup>2</sup>.

Then, the electrode A was hot-pressed to both sides of an ion-exchange membrane (Nafion manufactured by Dupont and having a thickness of 50 μm) at 140°C. Then, this membrane-electrode assembly was introduced into a single fuel cell holder so that cell A was obtained.

#### [Example 2]

Paste composed of platinum supported on carbon (10V30E: 30wt% Pt; Valcan XC-72 manufactured by Tanaka Kikinzoku) and solid polymer electrolyte solution (5 wt% Nafion solution manufactured by Ardrich) was applied onto a polymer film (PFA) as a blank to form the film of the paste. Then, the paste was naturally dried for about one hour so that a catalyst layer was formed. The catalyst layer was hot-pressed to both sides of an ion-exchange membrane (Nafion manufactured by Dupont and having a thickness of 50 μm) at 140°C, and then the blank was removed away. Thus,

a membrane-catalyst layer assembly was manufactured. Then, the surface of the catalyst layer of the assembly was coated with PVdF/MMP solution (the concentration of PVdF: 15 wt%) by using a brush. Then, the assembly was immersed in water for 10 minutes so that a membrane-catalyst layer assembly B was manufactured.

The assembly B has a structure in which the porous PVdF polymer is provided mainly for the surface of the catalyst layer.

The amount of the platinum supported on carbon in the paste was adjusted when the paste was prepared so that the amount of platinum loading in either side of the assembly B was about  $1.0 \text{ mg/cm}^2$ .

A carbon papers (0.5 mm), which served as a gas diffusion layer and to which hydrophobicity was imparted, were hot-pressed to the surface of the each catalyst layer. Then, the assembly was introduced into a single fuel cell holder so that cell B was manufactured.

[Comparative Example 1]

Paste composed of platinum supported on carbon (10V30E: 30wt%Pt supported on Valcan XC-72 manufactured by Tanaka Kikinzoku), solid polymer electrolyte solution (5 wt% Nafion solution manufactured by Ardrich) and PTFE suspension (Teflon 30J manufactured by Mitsui-Dupont Fluorochemical) was applied onto a hydrophobic porous paper (0.5 mm) as an electro-conductive porous substrate to form a film of the paste. Then, the paste was dried for about one hour at  $120^\circ\text{C}$

in a nitrogen atmosphere so that electrode C for a fuel cell was obtained.

The amount of the platinum supported on carbon in the paste was adjusted when the paste was prepared so that the amount of platinum loading in the electrode C was about 1.0 mg/cm<sup>2</sup>.

Then, the electrode C was hot-pressed to both sides of an ion-exchange membrane (Nafion manufactured by Dupont and having a thickness of 50 m) at 140°C. Then, the membrane-electrode assembly was introduced into a single fuel cell holder so that cell C was manufactured.

[Comparative Example 2]

Paste composed of platinum supported on carbon (10V30E: 30wt%Pt supported on Valcan XC-72 manufactured by Tanaka Kikinzoku), solid polymer electrolyte solution (5 wt% Nafion solution manufactured by Ardrich) and PTFE suspension (Teflon 30J manufactured by Mitsui-Dupont Fluorochemical) was applied onto a polymer film (PFA). Then, the paste was naturally dried for about one hour so that a catalyst layer was manufactured. Then, the catalyst layer was hot-pressed to both sides of an ion-exchange membrane (Nafion manufactured by Dupont and having a thickness of 50 m) at 140°C and then the blank was removed away so that a assembly D was manufactured. The amount of the platinum in the paste was adjusted when the paste was prepared so that the amount of platinum in both sides of assembly D was about 1.0 mg/cm<sup>2</sup>.

A porous carbon paper (0.5 mm) which served as a gas diffusion layer, to which hydrophobicity was imparted, was hot-pressed to the surface of each of the catalyst layer on the ion-exchange membrane. The assembly was introduced into  
5 a single fuel cell holder so that cell D was manufactured.

I-V characteristics for those cells on  $H_2/O_2$  are shown in Fig. 1. The operation conditions were such that the pressure of supplied reactant gases was 2 atm. Moreover, humidification of gases was carried out by bubbling in a  
10 closed water tank at 80°C. Each cell was operated at 75°C. Each current level was maintained for 5 minutes during the measurement.

As can be understood from Fig. 1, the cells (A and B) according to the present invention exhibited higher output  
15 voltages at each current density as compared with the conventional cells C and D. In particular, the cell A structured such that porous PVdF was provided for the inside portions of the pores in the catalyst layer and the surface of the same exhibited an output higher than that of the cell  
20 B. Since the electrode according to the present invention has the structure that the porous PVdF exhibiting high hydrophobicity was provided for the inside portions of the pores in the catalyst layer and/or the surface of the same, supply of hydrogen and oxygen as reactants to the deep  
25 portions of the electrode was enabled. Therefore, an active area of the catalyst layer was larger than that of the conventional catalyst layer. In particular, the cell A

having the structure that porous PVdF was provided for the inside portions of the pores of the catalyst layer and the surface of the same and inside of the carbon paper as the substrate, exhibited excellent characteristics.

5 [Example 3]

10 A porous carbon substrate (the thickness was 0.5 mm, an average fiber diameter was 10  $\mu$ m, an average diameter of pores was 10  $\mu$ m and the porosity was 75 %) was, in a vacuum, impregnated with PVdF/NMP solution (concentration of PVdF was 20 wt%). Then, the substrate was immersed in water for 10 minutes so that the porous carbon substrate including the porous PVdF was manufactured.

15 Then, paste composed of platinum supported on carbon (10V30E: 30wt% Pt supported on Valcan XC-72 manufactured by Tanaka Kikinzoku), solid polymer electrolyte solution (5 wt% Nafion solution manufactured by Ardrich) and PTFE suspension (Teflon 30J manufactured by Mitsui-Dupont Fluorochemical) was applied onto the surface of the above-mentioned porous carbon substrate by performing a spraying method so that  
20 electrode E for a fuel cell was manufactured.

The amount of the platinum supported on carbon in the paste was adjusted when the paste was prepared so that the amount of platinum in the electrode E was about  
1.0 mg/cm<sup>2</sup>.

25 The electrode E was hot-pressed to both sides of an ion-exchange membrane (Nafion manufactured by Dupont and having a thickness of 50  $\mu$ m) at 140°C. This membrane-

electrode assembly was introduced into a single fuel cell holder so that cell E was manufactured.

[Example 4]

A porous carbon paper as a substrate (the thickness was 0.5 mm, an average fiber diameter was 10  $\mu$ m, an average diameter of pores was 10  $\mu$ m and the porosity was 75 %) was impregnated with P(VdF-HFP)/MEK solution (the concentration of PVdF-HFP was 10 wt%) at 75°C. Then, the substrate including P(VdF-HFP)/MEK solution was dry in thermostatic oven at 30°C so that MEK was removed. Thus, the porous carbon substrate including the porous P(VdF-HFP) was manufactured by the phase inversion process.

Then, paste composed of platinum supported on carbon (10V30E: 30wt% Pt supported on Valcan XC-72 manufactured by Tanaka Kikinzoku), solid polymer electrolyte solution (5 wt% Nafion solution manufactured by Ardrich) and PTFE suspension (Teflon 30J manufactured by Mitsui-Dupont Fluorochemical) was applied to the above-mentioned carbon substrate by a spraying method so that electrode F for a fuel cell was manufactured.

The amount of the platinum loading in the electrode was adjusted when the paste was prepared so that the amount of platinum loading in the electrode F was about 1.0 mg/cm<sup>2</sup>.

The electrode F was hot-pressed to both sides of an ion-exchange membrane (Nafion manufactured by Dupont and having a thickness of 50  $\mu$ m). This membrane-electrode

assembly was introduced into a single fuel cell holder so that cell F was manufactured.

[Comparative Example 3]

A porous carbon substrate (the thickness was 0.5 mm, an average fiber diameter was 10  $\mu$ m, an average diameter of pores was 10  $\mu$ m and the porosity was 75 %), to which hydrophobicity was imparted with PTFE suspension, was dispersed was applied with paste composed of platinum supported on carbon (10V30E: 30wt% Pt supported on Valcan XC-72 manufactured by Tanaka Kikinzoku), solid polymer electrolyte solution (5 wt% Nafion solution manufactured by Ardrich) and PTFE suspension (Teflon 30J manufactured by Mitsui-Dupont Fluorochemical) by a spraying method so that electrode F for a fuel cell was manufactured.

The amount of the platinum supported on carbon in the paste was adjusted when the paste was prepared so that the amount of platinum in the electrode F was about 1.0 mg/cm<sup>2</sup>.

The electrode F was hot-pressed onto both sides of an ion-exchange membrane (Nafion manufactured by Dupont and having a thickness of 50  $\mu$ m) at 140°C. The membrane-electrode assembly was introduced into a single fuel cell holder so that cell G was manufactured.

I-V characteristics of the cells (E, F and G) on H<sub>2</sub>/O<sub>2</sub> were measured. The I-V characteristics for the cell (E) and cell (G) were shown in Fig. 2. Note that the I-V characteristics of the cell (F) according to the present invention were similar to those of the cell (E) according

to the present invention. The operation conditions were such that the pressure of supplied gases were 1.8 atm pressures. Moreover, humidification of gases was carried out by bubbling in a closed water tank set to 85°C to perform wetting. Each cell was operated at 78°C. Each current level was maintained for 5 minutes during the measurement.

As can be understood from Fig. 2, the cells (E and F) according to the present invention exhibited higher output voltage at each current density as compared with the conventional cell (G). Since the conventional electrode had the structure that the thickness of the catalyst layer was uniform, so ineffective portions were distributed in the catalyst layer. On the other hand, each of the electrodes according to the present invention had the structure that the thickness of each of the catalyst layer of the electrode was controlled to be constant (5  $\mu$ m to 10  $\mu$ m). Therefore, the overall portion of the catalyst layer acted effectively so that the electrochemically active area of the catalyst layer of the electrode was larger than that of the conventional catalyst layer of the electrode.

[Example 5]

A porous carbon substrate (the thickness was 0.5 mm, an average fiber diameter was 10  $\mu$ m, an average diameter of pores was 10  $\mu$ m and the porosity was 75 %) was, in vacuum, impregnated with 20wt% P(VdF-HFP)(HFP: 6 wt%)/NMP solution. Then, the substrate including P(VdF-HFP)/NMP solution was immersed in water for 10 minutes so that a porous carbon



substrate including the porous P(VdF-HFP) was obtained. Then, the porous carbon substrate was exposed in a mixed-gas atmosphere in which 10% fluorine gas - 90% nitrogen gas for 20 minutes. Thus, carbon substrate including a porous

5 carbon substrate including the fluorinated porous fluorocarbon polymer P(VdF-HFP) was manufactured. Then, paste composed of platinum supported on carbon (10V30E: 30wt% Pt supported on Valcan XC-72 manufactured by Tanaka Kikinzoku), solid polymer electrolyte solution (5 wt% Nafion

10 solution manufactured by Ardrich) and solution PTFE suspension (Teflon 30J manufactured by Mitsui-Dupont Fluorochemical) was applied onto the porous carbon substrate to form the film of the paste so that electrode H for a fuel cell was manufactured. The amount of the platinum supported

15 on carbon was adjusted when the paste was prepared so that the amount of platinum loading in the electrode H was about 1.0 mg/cm<sup>2</sup>.

The electrode H was hot-pressed onto both sides of an ion-exchange membrane (Nafion manufactured by Dupont and

20 having a thickness of 50 μm) at 140°C. This membrane-electrode assembly was introduced into a single fuel cell holder so that cell H was manufactured.

[Comparative Example 4]

A porous carbon paper as a substrate (0.5 mm) to which

25 hydrophobicity was imparted by coating with PTFE suspension (Teflon 30J manufactured by Mitsui-Dupont Fluorochemical) was coated with paste including platinum supported on carbon

(10V30E: 30wt% Pt supported on Valcan XC-72 manufactured by Tanaka Kikinzoku), solid polymer electrolyte solution (5 wt% Nafion solution manufactured by Ardrich) and PTFE suspension (Teflon 30J manufactured by Mitsui-Dupont Fluorochemical) so that electrode I for a fuel cell was manufactured. The amount of the platinum supported on carbon was adjusted when the paste was prepared so that the amount of platinum loading in the electrode I was about  $1.0 \text{ mg/cm}^2$ . Then, the electrode I was hot-pressed onto both sides of an ion-exchange membrane (Nafion manufactured by Dupont and having a thickness of 50  $\mu\text{m}$ ) at  $140^\circ\text{C}$ . This membrane-electrode assembly was introduced into a single fuel cell holder so that cell I was manufactured.

I-V characteristics of the cells (H and I) on  $\text{H}_2/\text{O}_2$  were shown in Fig. 3. The operation conditions were such that the pressure of supplied reactant gases was 3 atm. Moreover, humidification of gases was carried out by bubbling in a closed water tank at  $80^\circ\text{C}$ . Each cell was operated at  $60^\circ\text{C}$ . Each current level was maintained for 10 minutes during the measurement.

As can be understood from Fig. 3, the cell (H) according to the present invention exhibited output voltages higher than those of the conventional cell (I) in a high current density region. The electrode according to the present invention incorporated the porous carbon substrate contains porous polymers obtained by fluorinating P(VdF-HFP). Therefore, excellent hydrophobicity and gas diffusivity

were simultaneously imparted to the electrode. On the other hand, the conventional electrode incorporated the porous carbon substrate coated with PTFE particles. Therefore, the conventional electrode having excellent hydrophobicity and poor gas diffusivity because the pores in the substrate were closed by PTFE particles.

The electrode for a fuel cell according to the present invention including the porous polymer shows simultaneously excellent hydrophobicity and gas diffusivity. Furthermore, the thickness of the catalyst layer was maintained uniformly, therefore overall portion of the electrode is effective for electrochemical reactions. Hence it follows that the active area of the electrode can be enlarged as compared with that of the conventional electrode. As a result, a high-performance fuel cell can be manufactured. The manufacturing method according to the present invention is able to manufacture the electrode improving a high-performance for fuel cell can be manufactured.

WHAT IS CLAIMED IS:

1. An electrode for a fuel cell comprising: a catalyst layer and a porous polymer, said catalyst layer containing a solid polymer electrolyte and catalyst particles.

5

2. The electrode according to claim 1, wherein said porous polymer is provided for the inside portion of porous or/and surface of said catalyst layer.

10 3. An electrode for a fuel cell comprising: a catalyst layer and a gas diffusion layer and a porous polymer;

wherein said catalyst layer contains a solid polymer electrolyte and catalyst particles, and said gas diffusion layer containing an electro-conductive porous substrate.

15

4. The electrode according to claim 3, wherein said porous polymer is provided for the inside portion of pores or/and surface of said catalyst layer or/and inside of the electro-conductive porous substrate.

20

5. The electrode according to claim 1 or 3, wherein said porous polymer has no ion-exchange function.

25 6. The electrode according to claim 1 or 3, wherein pores of said porous polymer form the three-dimensional network structure.

7. The electrode according to claim 1 or 3, wherein an average diameter of pores in said porous polymer is 1  $\mu\text{m}$  or less.

5        8. The electrode according to claim 1 or 3, wherein an average diameter of pores in said porous polymer is 0.05  $\mu\text{m}$  or less.

10       9. The electrode according to claim 1 or 3, wherein a porosity of said porous polymer is the range of 45% to 95%.

10       10. The electrode according to claim 1 and 3, wherein said porous polymer is fluorocarbon polymer.

15       11. A method of manufacturing porous polymer comprising the step of: separating a polymer (a) from the solution (c) in which the polymer (a) is dissolved in a solvent (b) by the phase inversion process.

20       12. A method of manufacturing porous polymer comprising the step of: extracting a solvent (b) from the solution (c), in which a polymer (a) is dissolved in the solvent (b), with the non solvent (d) which is insoluble in the polymer (a) and miscible with the solvent (b).

25       13. A method of manufacturing an electrode for a fuel cell comprising the steps of:

preparing an electrode (j) comprising a catalyst layer containing a solid polymer electrolyte and catalyst particles;

preparing a solution (c) in which a polymer (a) is  
5 dissolved in a solvent (b);

allowing said solution (c) to be contained in said electrode; and

separating said polymer (a) from said solution.

10 14. A method of manufacturing an electrode for a fuel cell comprising the steps of:

preparing an electrode (j) comprising a catalyst layer containing a solid polymer electrolyte and catalyst particles;

15 preparing a solution (c) in which a polymer (a) is dissolved in a solvent (b);

allowing said solution (c) to be contained in said electrode; and

20 extracting said solvent (b) from the said solution (c) with a non solvent (d) which is insoluble in said polymer (a) and miscible with the solvent.

15 15. The method according to claim 13 or 14, wherein the electrode (j) further comprises a gas diffusion layer  
25 containing the electro-conductive porous substrate.

16. The method according to claim 13 or 14, wherein said electrode (j) is being joined to the ion-exchange membrane.

5 17. A method of manufacturing an electrode for a fuel cell comprising the steps of:

preparing a gas diffusion layer containing an electro-conductive porous substrate;

preparing a catalyst layer (k) containing a solid polymer electrolyte and catalyst particles;

preparing a solution (c) in which a polymer (a) is dissolved in a solvent (b);

allowing said solution (c) to be contained in said gas diffusion layer;

15 separating said polymer (a) from said solution (c); and joining said gas diffusion layer to said catalyst layer (k).

20 18. A method of manufacturing an electrode for a fuel cell comprising the steps of:

preparing a gas diffusion layer containing an electro-conductive porous substrate;

preparing a catalyst layer (k) containing a solid polymer electrolyte and catalyst particles;

25 preparing a solution (c) in which a polymer (a) is dissolved in a solvent (b);

allowing said solution (c) to be contained in said gas diffusion layer;

extracting said solvent (b) from said solution (c) with a non solvent (d) which is insoluble in said polymer (a) and  
5 miscible with the solvent (b); and

joining said gas diffusion layer to said catalyst layer (k).

10 19. The method according to claim 17 or 18, wherein said catalyst layer (k) is being joined to the ion-exchange membrane.

20. The method according to claim 17 or 18, further comprising the step of: fluorinating said porous polymer.



ABSTRACT OF THE DISCLOSURE

In an electrode for a fuel cell, a catalyst layer contains a solid polymer electrolyte, catalyst particles and porous polymer. The porous polymer is provided for the inside portions of pores of said catalyst layer and/or the surface of said catalyst layer.

5

Fig. 1

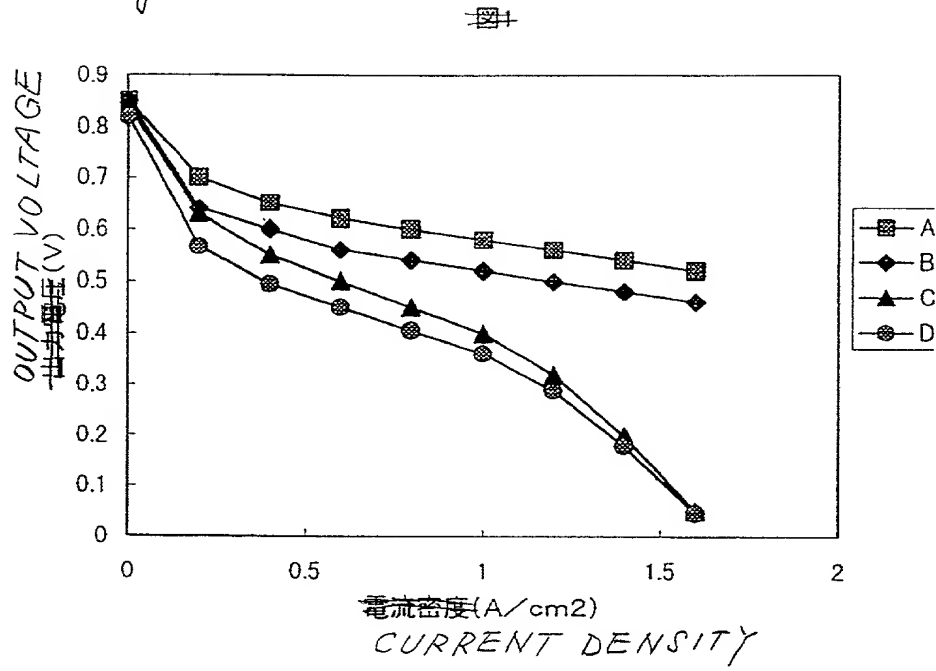


Fig.2

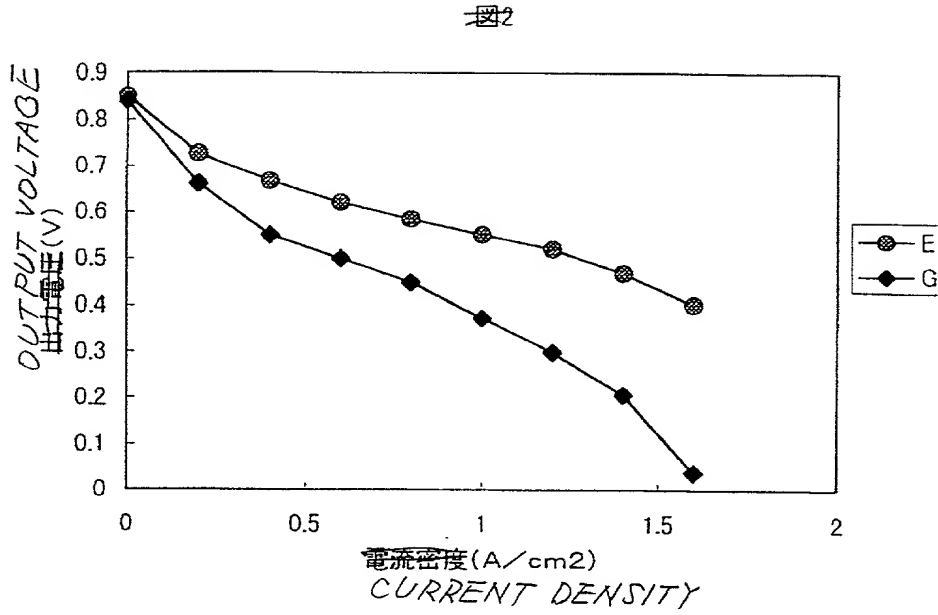


Fig.3

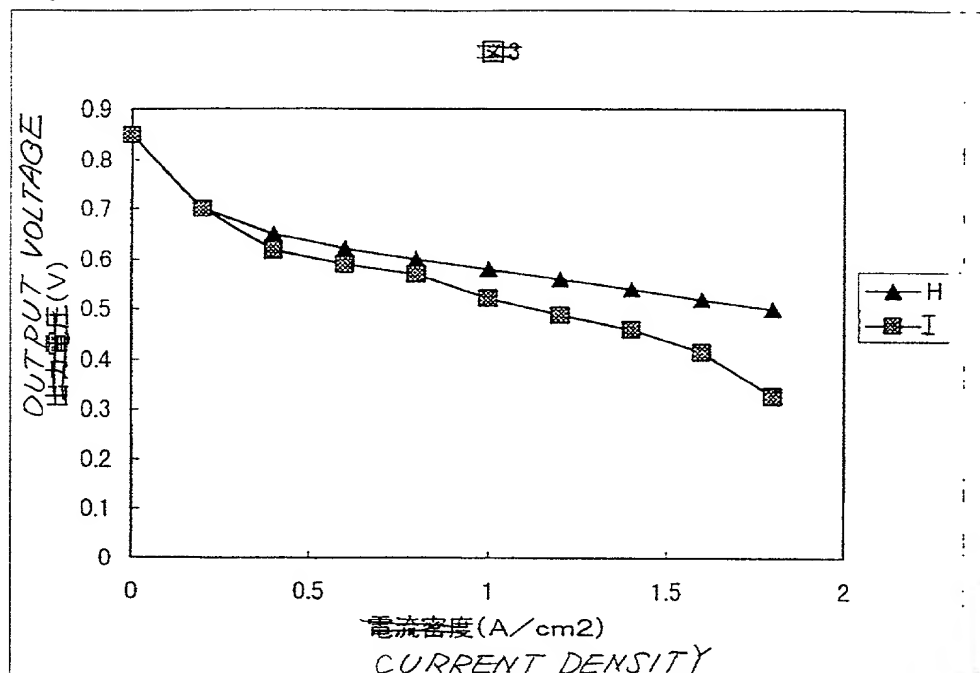


Fig 4

4  
[図 4]

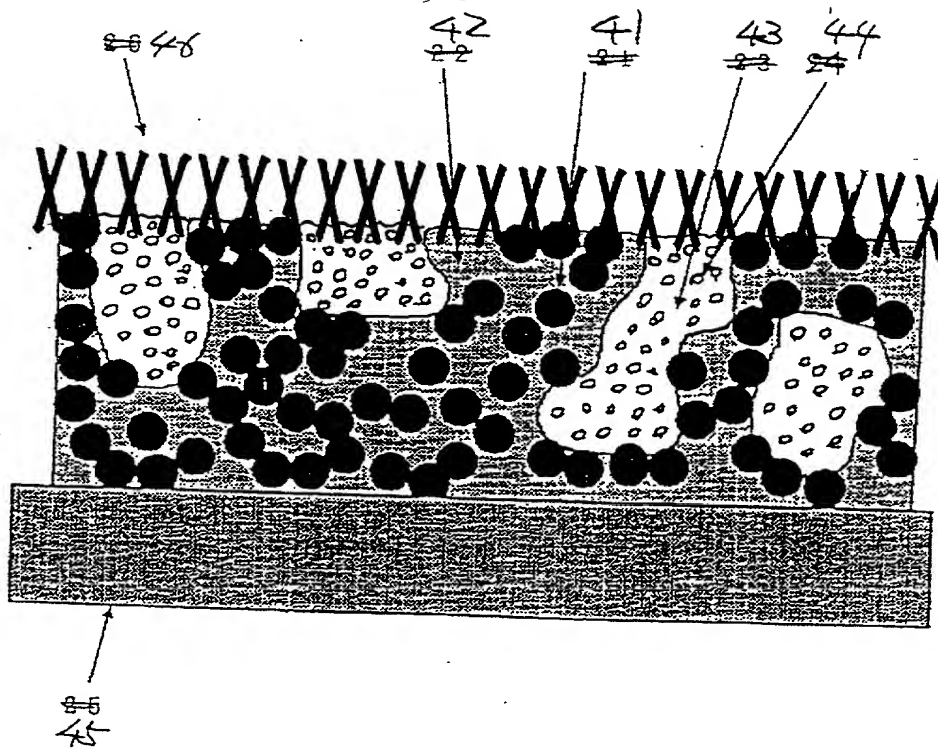


Fig.5 (図5)

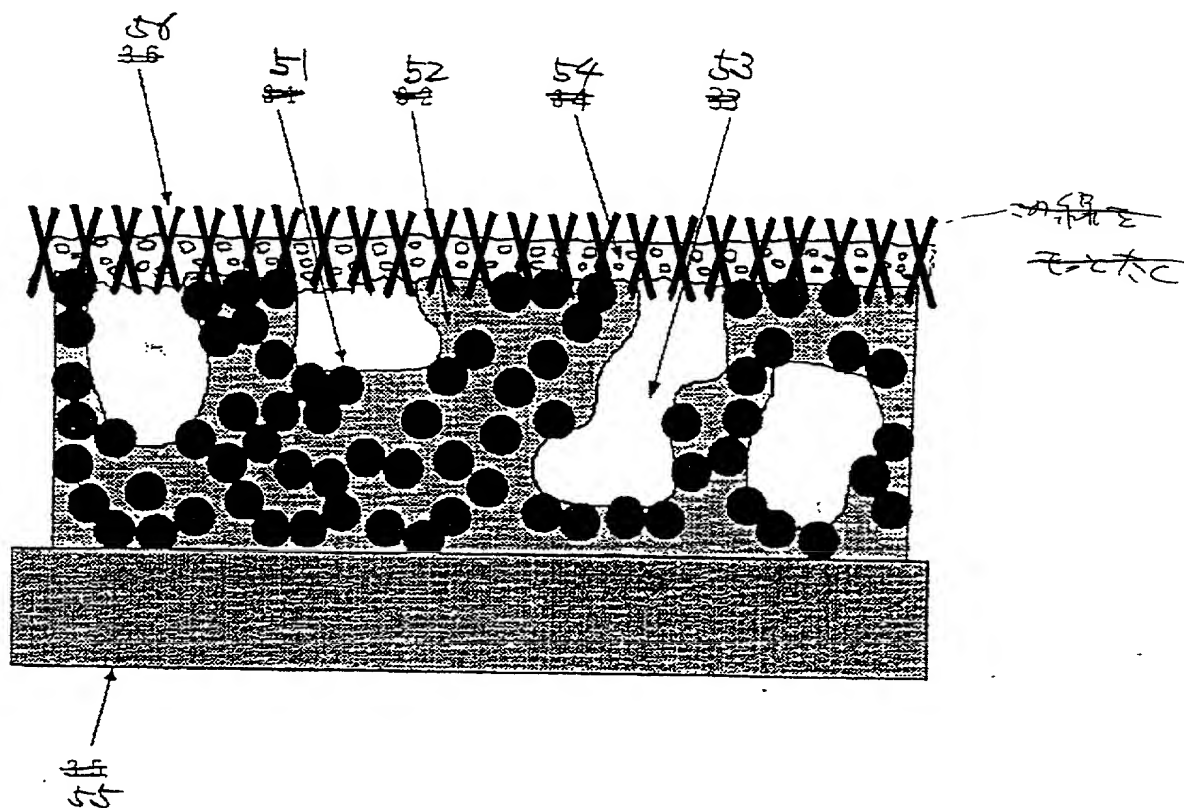
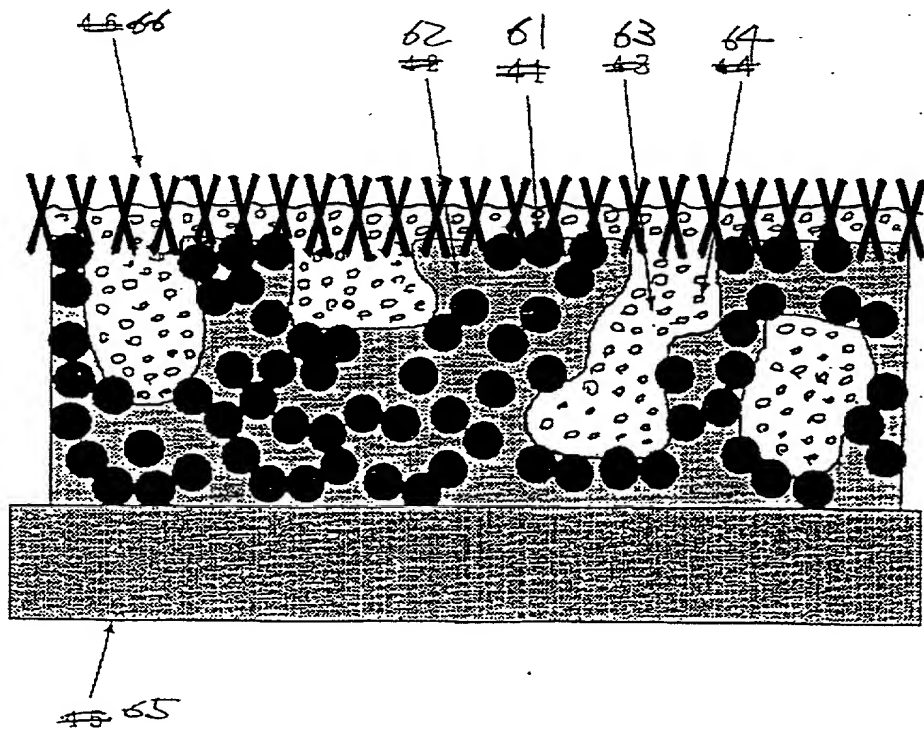


Fig. 6 [図6]



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~~Fig. 7~~  
Fig. 7

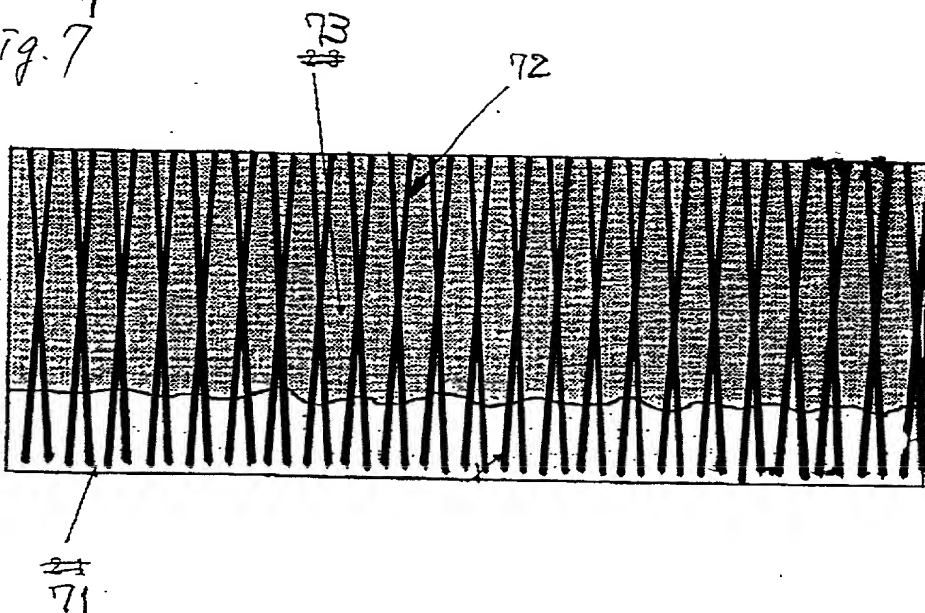
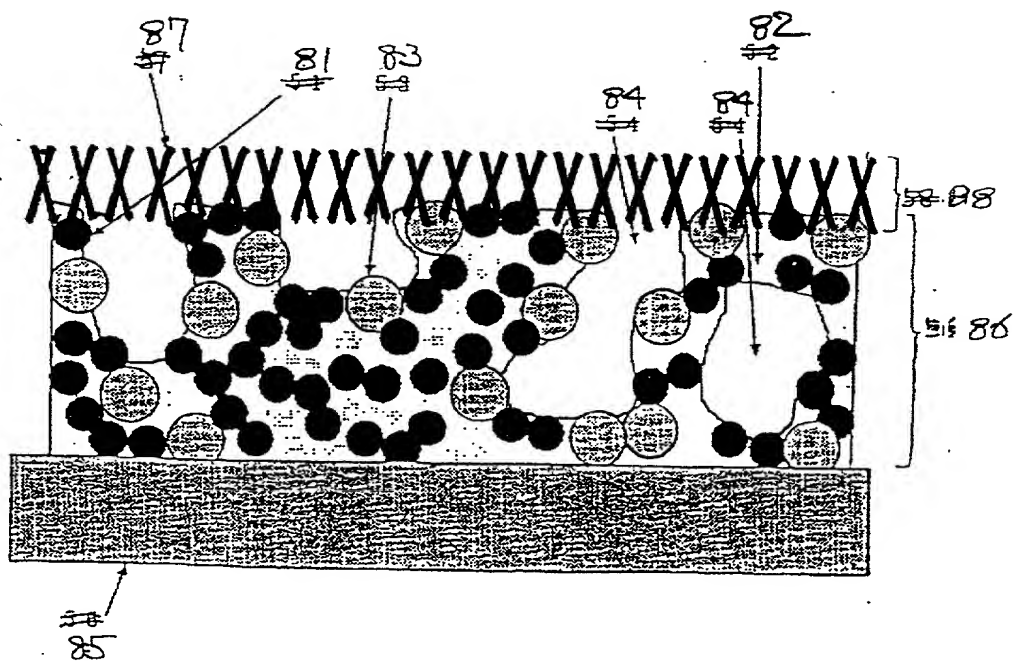




Fig. 8

~~8~~  
~~10/1~~



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【図8】

Fig. 9

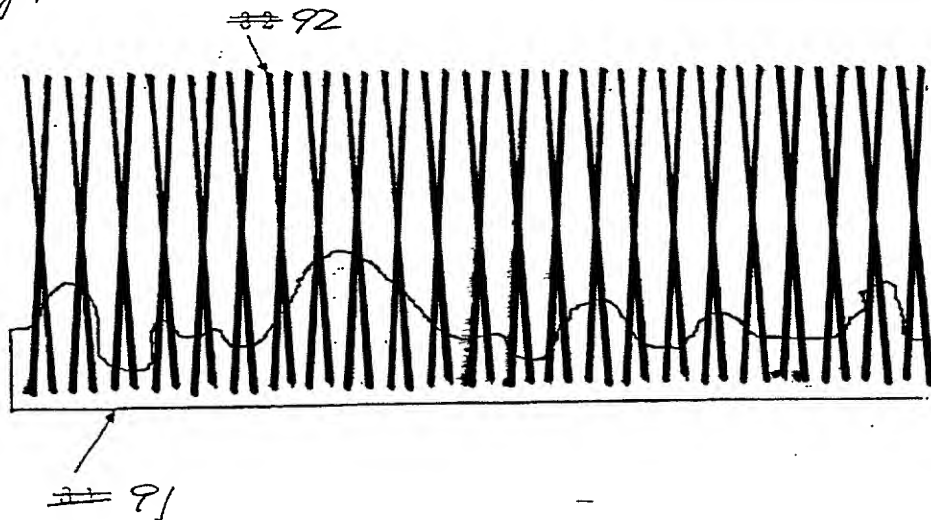
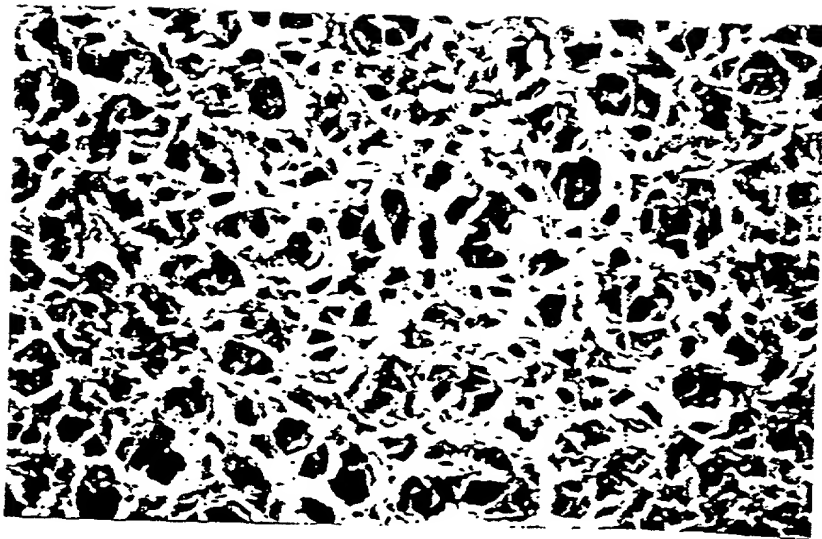


Fig. 10



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# DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

## ELECTRODE FOR FUEL CELL AND MANUFACTURING METHOD THEREFOR

the specification of which is attached hereto unless the following box is checked:

☐ was filed on \_\_\_\_\_ as United States Application Number or PCT International Application Number \_\_\_\_\_ and was amended on \_\_\_\_\_ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information of which is material to the patentability as defined in 37 CFR § 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)

Priority Not Claimed

<u>P.Hei. 11-29045</u> (Number)	<u>Japan</u> (Country)	<u>05/February/1999</u> (Day/Month/Year Filed)	<input type="checkbox"/>
<u>P.Hei. 11-78885</u> (Number)	<u>Japan</u> (Country)	<u>24/March/1999</u> (Day/Month/Year Filed)	<input type="checkbox"/>
<u>P.Hei. 11-78889</u> (Number)	<u>Japan</u> (Country)	<u>24/March/1999</u> (Day/Month/Year Filed)	<input type="checkbox"/>

I hereby claim the benefits under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below.

(Application Number)

(Filing Date)

I hereby claim the benefits under 35 U.S.C. § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

(Application Number)

(Filing Date)

(Status - patented, pending, abandoned)

(Application Number)

(Filing Date)

(Status - patented, pending, abandoned)

I hereby appoint John H. Mion, Reg. No. 18,879; Thomas J. Macpeak, Reg. No. 19,292; Robert J. Seas, Jr., Reg. No. 21,092; Darryl Mexic, Reg. No. 23,063; Robert V. Sloan, Reg. No. 22,775; Peter D. Olexy, Reg. No. 24,513; J. Frank Osha, Reg. No. 24,625; Waddell A. Biggart, Reg. No. 24,861; Louis Gubinsky, Reg. No. 24,835; Neil B. Siegel, Reg. No. 25,200; David J. Cushing, Reg. No. 28,703; John R. Inge, Reg. No. 26,916; Joseph J. Ruch, Jr., Reg. No. 26,577; Sheldon I. Landsman, Reg. No. 25,430; Richard C. Turner, Reg. No. 29,710; Howard L. Bernstein, Reg. No. 25,665; Alan J. Kasper, Reg. No. 25,426; Kenneth J. Burchfiel, Reg. No. 31,333; Gordon Kit, Reg. No. 30,764; Susan J. Mack, Reg. No. 30,951; Frank L. Bernstein, Reg. No. 31,484; Mark Boland, Reg. No. 32,197; William H. Mandir, Reg. No. 32,156; Scott M. Daniels, Reg. No. 32,562; Brian W. Hannon, Reg. No. 32,778; Abraham J. Rosner, Reg. No. 33,276; Bruce E. Kramer, Reg. No. 33,725; Paul F. Neils, Reg. No. 33,102; Brett S. Sylvester, Reg. No. 32,765 and Robert M. Masters, Reg. No. 35,603; my attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith, and request that all correspondence about the application be addressed to SUGHRUE, MION, ZINN, MACPEAK & SEAS, PLLC, 2100 Pennsylvania Avenue, N.W., Washington, D.C. 20037.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date February 1, 2000

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